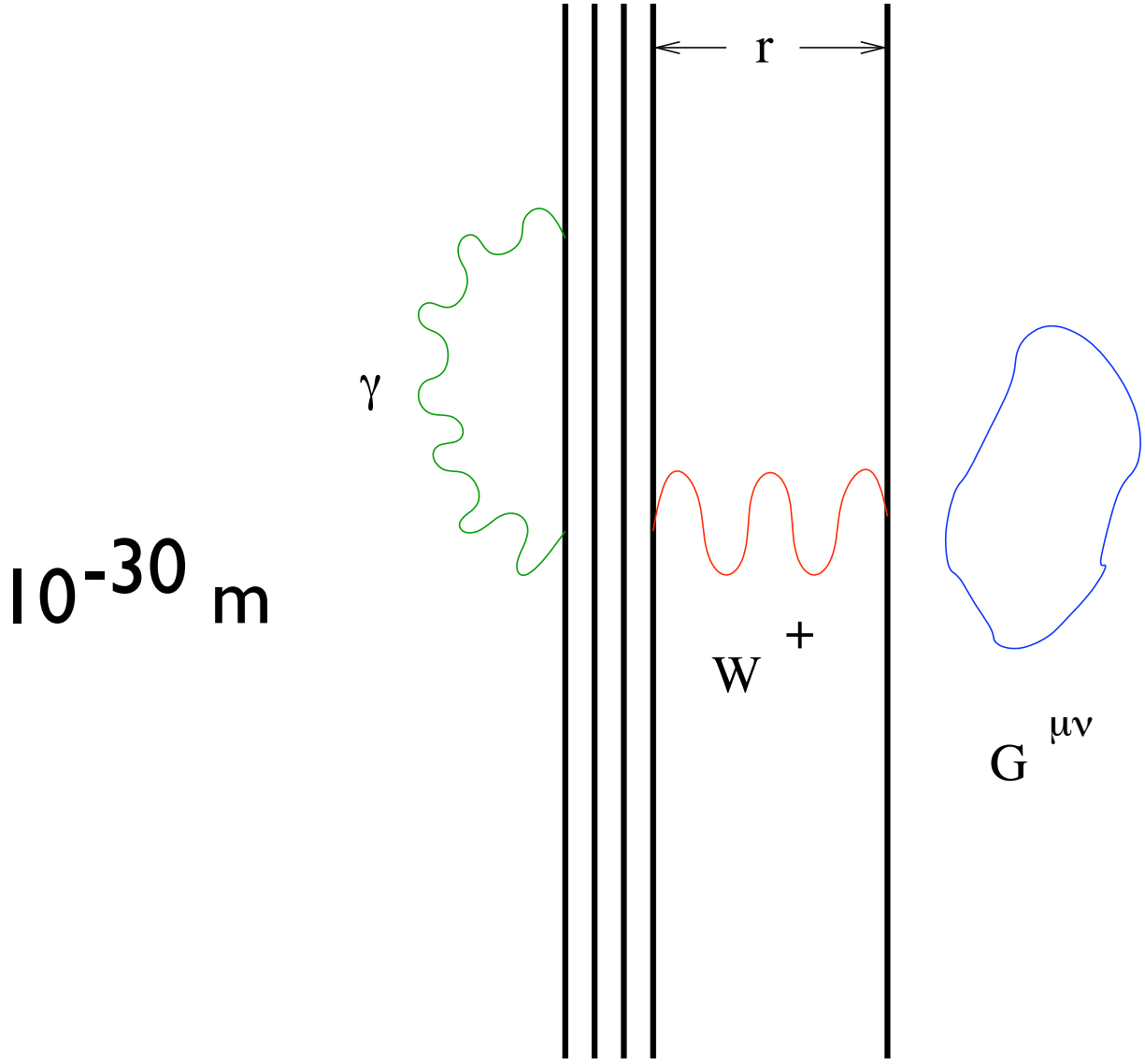
Cosmic Strings: an Update

Henry Tye

Cornell University

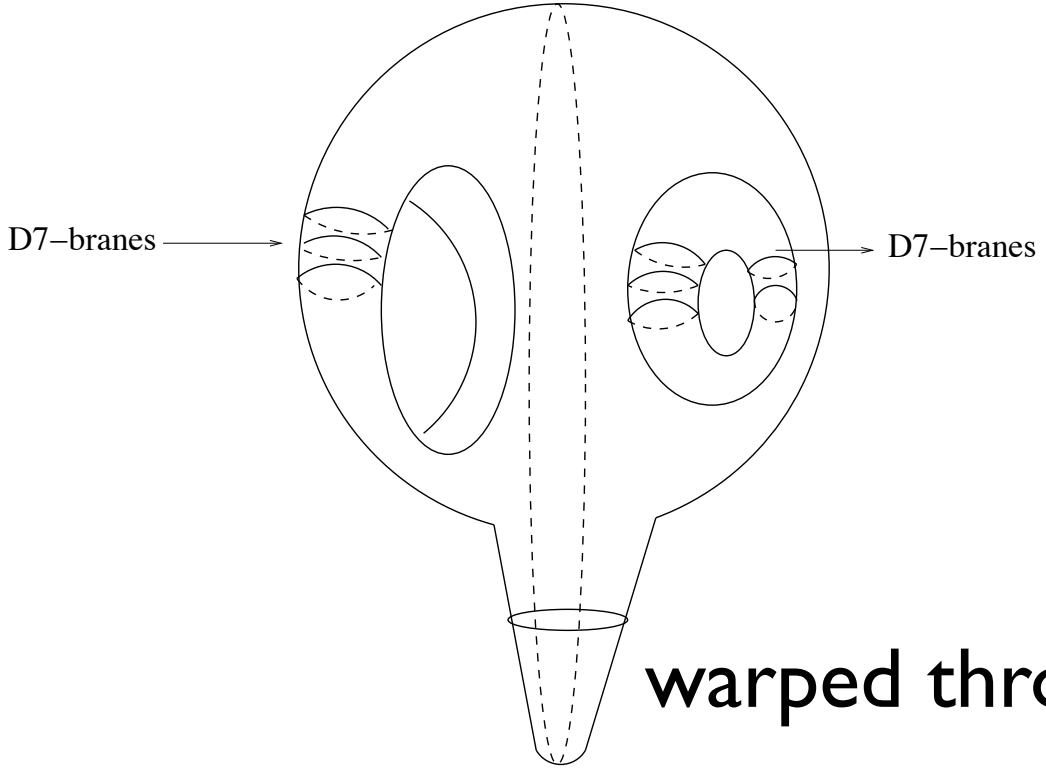
String Phenomenology, KITP, 8/28/06

Brane world



Flux compactification

where all moduli of the 6-dim. manifold are stabilized



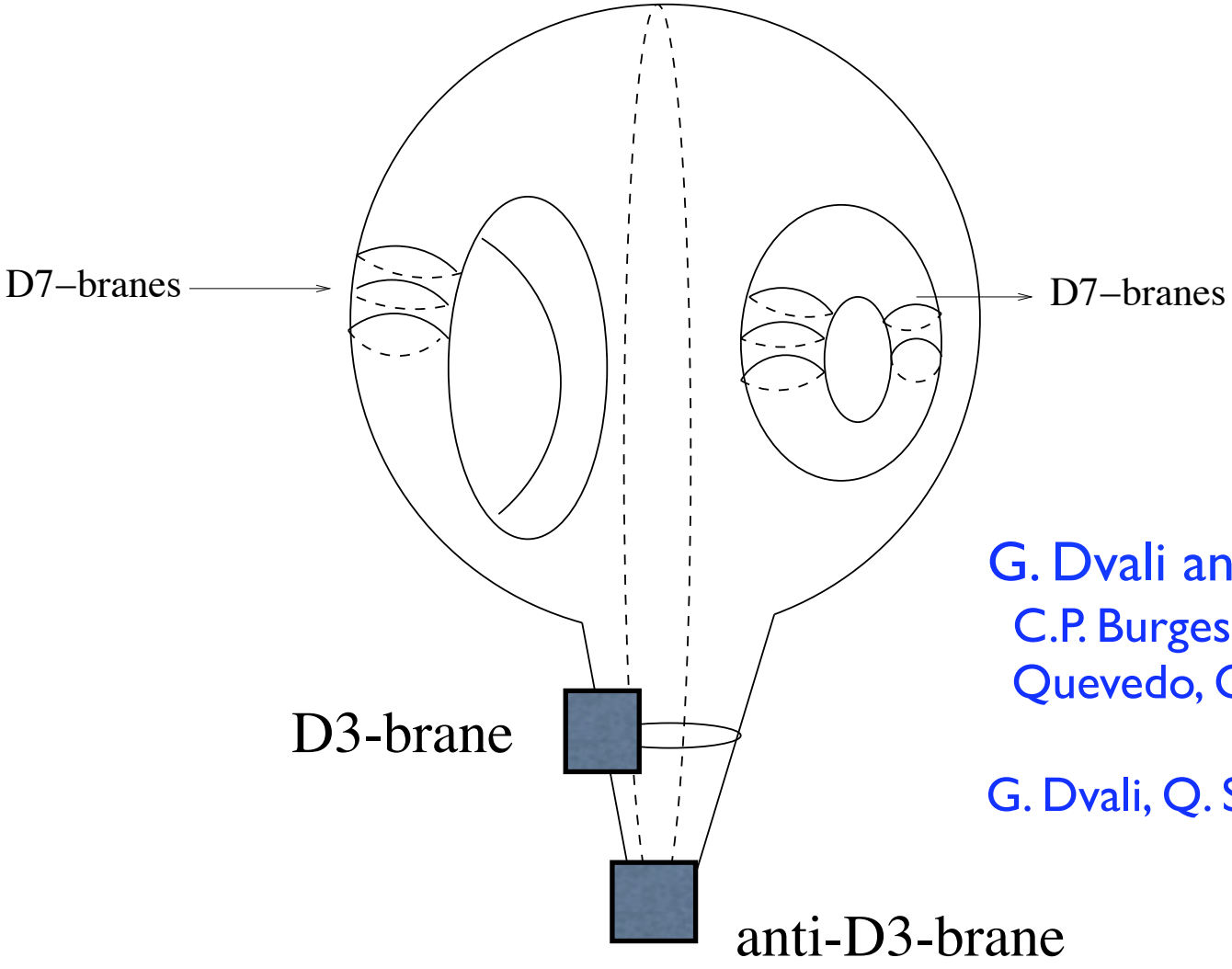
warped throat

Giddings, Kachru, Polchinski
Kachru, Kallosh, Linde, Trivedi

and many others

KKLT vacuum

D3-anti-D3 brane inflation



G. Dvali and H.T. , hep-ph/9812483

C.P. Burgess, M. Majumdar, D. Nolte, F. Quevedo, G. Rajesh, R. Zhang, hep-th/0105204

G. Dvali, Q. Shafi and S. Solganik, hep-th/0105203

KKLMMT Scenario

Kachru, Kallosh, Linde, Maldacena, MacAllister, Trivedi, hep-th/0308055

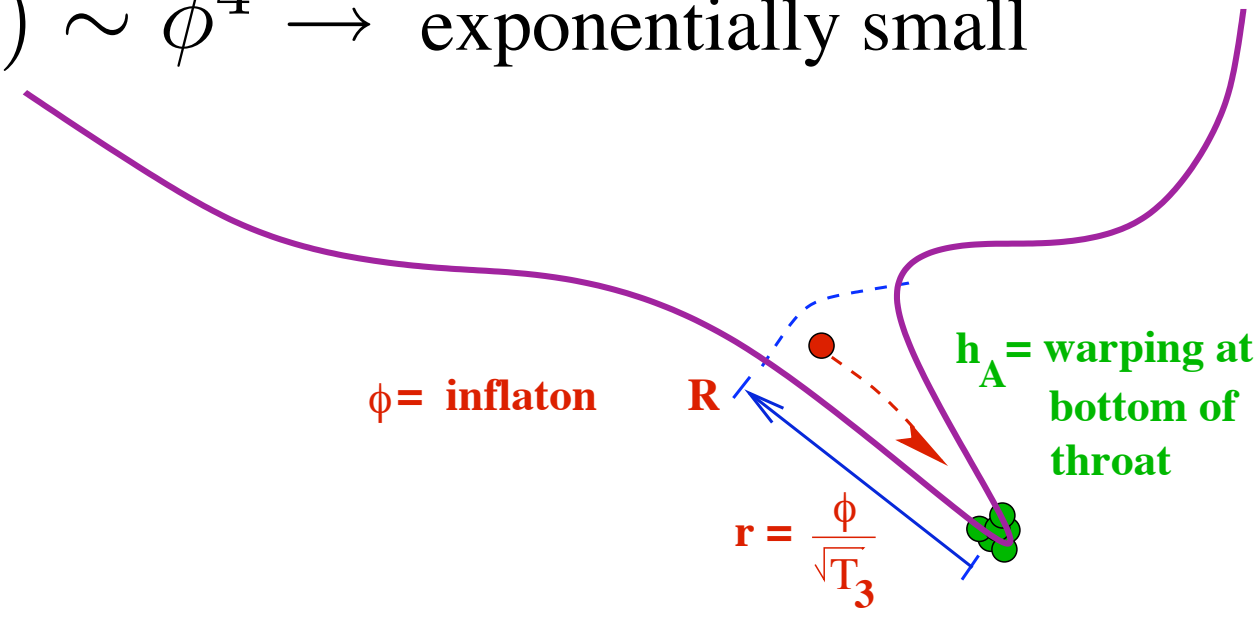
Why brane inflation is so robust ?

$$S = -\int d^4x\, a^3(t) \left[T\sqrt{1-\dot{\phi}^2/T} + V(\phi) - T \right]$$

Dirac-Born-Infeld action yields Lorentz factor :

$$\gamma = \frac{1}{\sqrt{1-\dot{\phi}^2/T}} \quad \rightarrow \quad \dot{\phi}^2 < T(\phi)$$

$$T(\phi) \sim \phi^4 \rightarrow \text{ exponentially small}$$

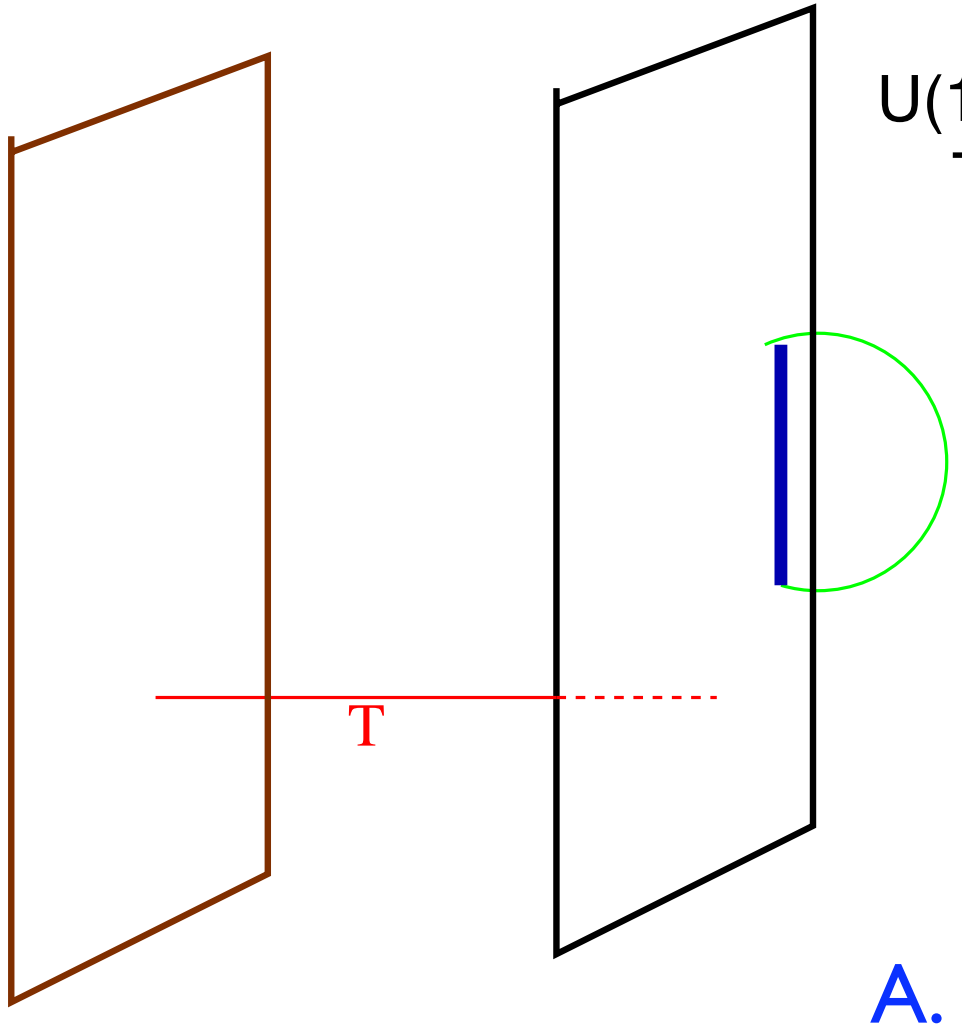


E. Silverstein and D. Tong, hep-th/0310221

Production of cosmic strings

towards the end of brane inflation

from the D3-anti-D3 annihilation



U(1)xU(1) gauge group:
T couples to U(1)_

confining $U(1)_+$

A. Sen, P.Yi, . . .

Production of cosmic strings not guaranteed

- there are scenarios where no cosmic strings are produced
- or strings produced are not stable while stable strings are not produced
- parametric resonance production of pairs of closed strings (Gubser): $\rho_{loop} > \mu/l^2$

Well-known cosmological properties

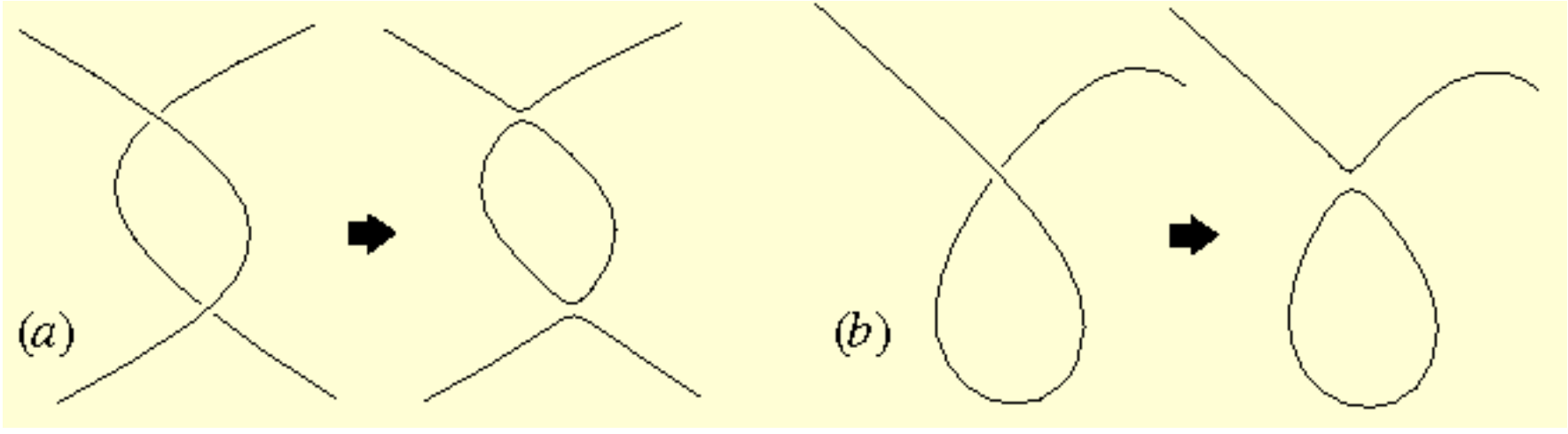
- Monopoles : density ~ a^{-3} Disastrous
- Domain walls : density ~ 1/a Disastrous
- cosmic strings : density ~ a^{-2}
  interaction cuts it down to a^{-4} during radiation

$$G\mu < 10^{-6}$$

N. Jones, H. Stoica, H.T., hep-th/0203163
S. Sarangi , H.T., hep-th/0204074

Cosmic strings

- Cosmic string interactions



Cosmic String Network Evolution

Allen, Martins & Shellard

History of cosmic strings

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History of cosmic strings

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- Brane world/brane inflation leads to a revival of cosmic strings. Realistic realization of brane world/inflation are known : KKLT and KKLMMT and other scenarios.

Uncertainties in the amount of sub-horizon loops

$$\Omega_{cs} = \Omega_\infty + \Omega_{loop} = 50 G\mu + \chi\sqrt{\alpha}\sqrt{G\mu}$$

$$\chi \sim 100$$

The typical size of the loops is parameterized as αt

$$\alpha \sim 0.25, 0.1, 10^{-4}, 50G\mu, (50G\mu)^{5/2}$$

V. Vanchurin, K. Olum and A. Vilenkin, gr-qc/0501040, 0511159

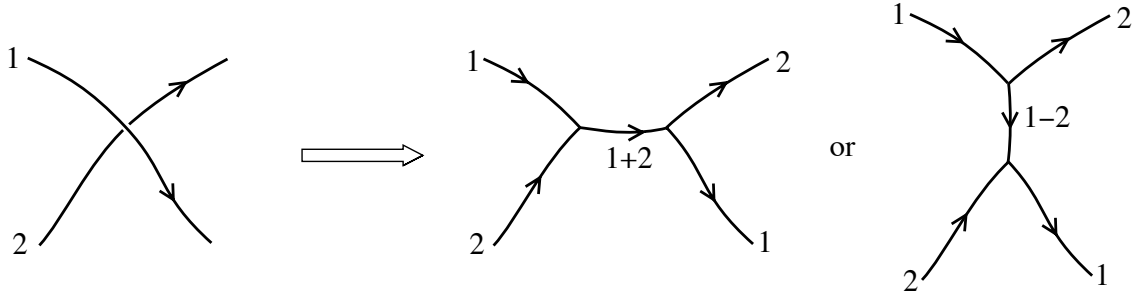
C. Ringeval, M. Sakellariadou and F. Bouchet, astro-ph/0511646

C. Martin and E.P. Shellard, astro-ph/0511792

J. Polchinski and J. Rocha, hep-ph/0606205

(p,q) Superstrings

- In contrast to vortices in Abelian Higgs model, cosmic strings from brane inflation should have a spectrum in tension.
- This is the (p,q) strings, where p and q are coprime. (1,0) strings are fundamental strings while (0,1) strings are D1-strings.
- The spectrum depends on the particular brane inflationary scenario.



$$G\mu_{p,q} = \sqrt{p^2 g_s^2 + q^2} G\mu$$

They have non-trivial interactions.

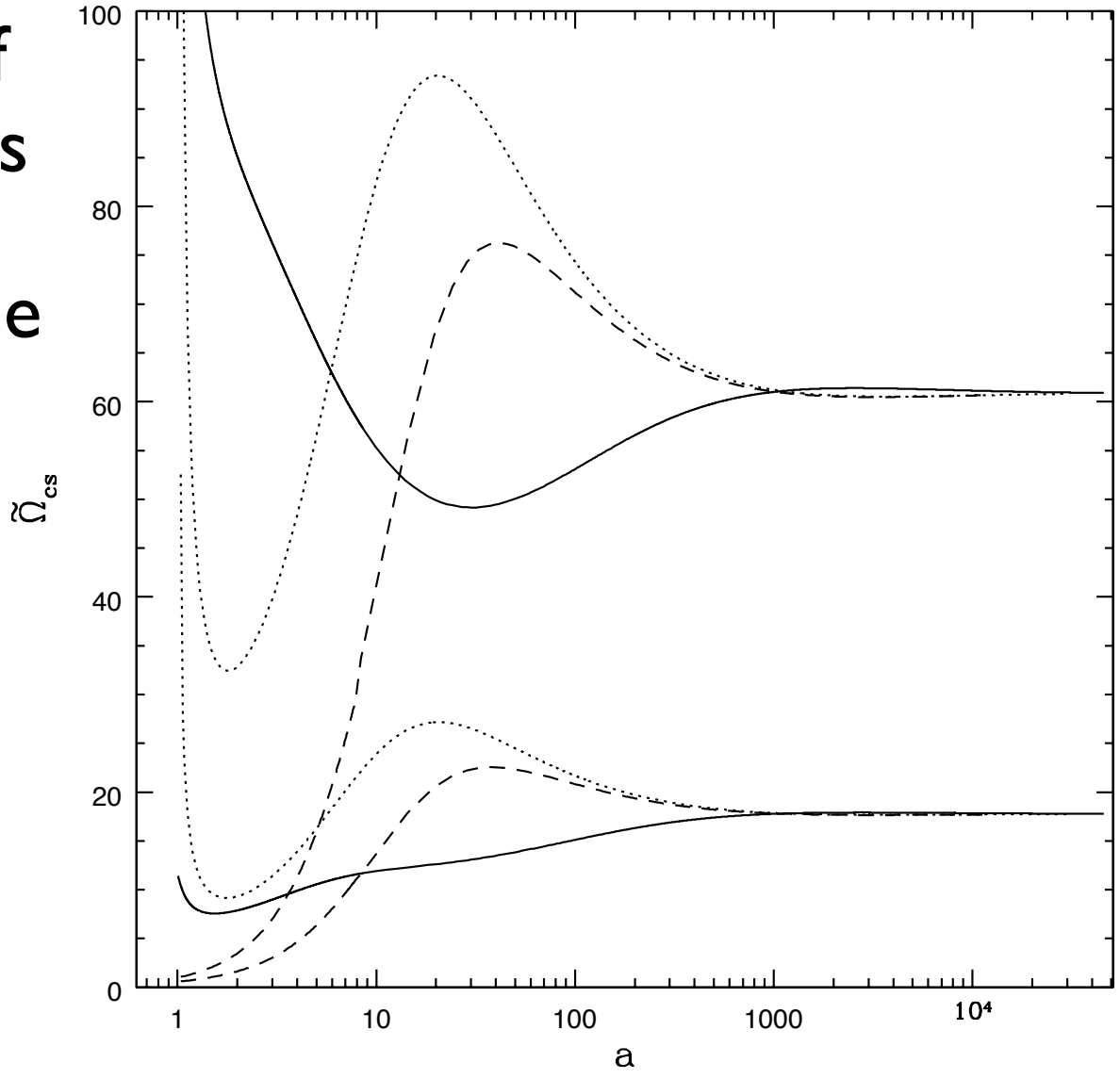
E. Copeland, R. Myers and J. Polchinski, hep-th/0312067
G. Dvali and A. Vilenkin, hep-th/0312004

Scaling of the Cosmic Superstring Network

independent of initial conditions

Insensitive to the details of the interactions

$$\Omega_{cs} = \frac{10\Gamma G\mu}{g_s^2}$$

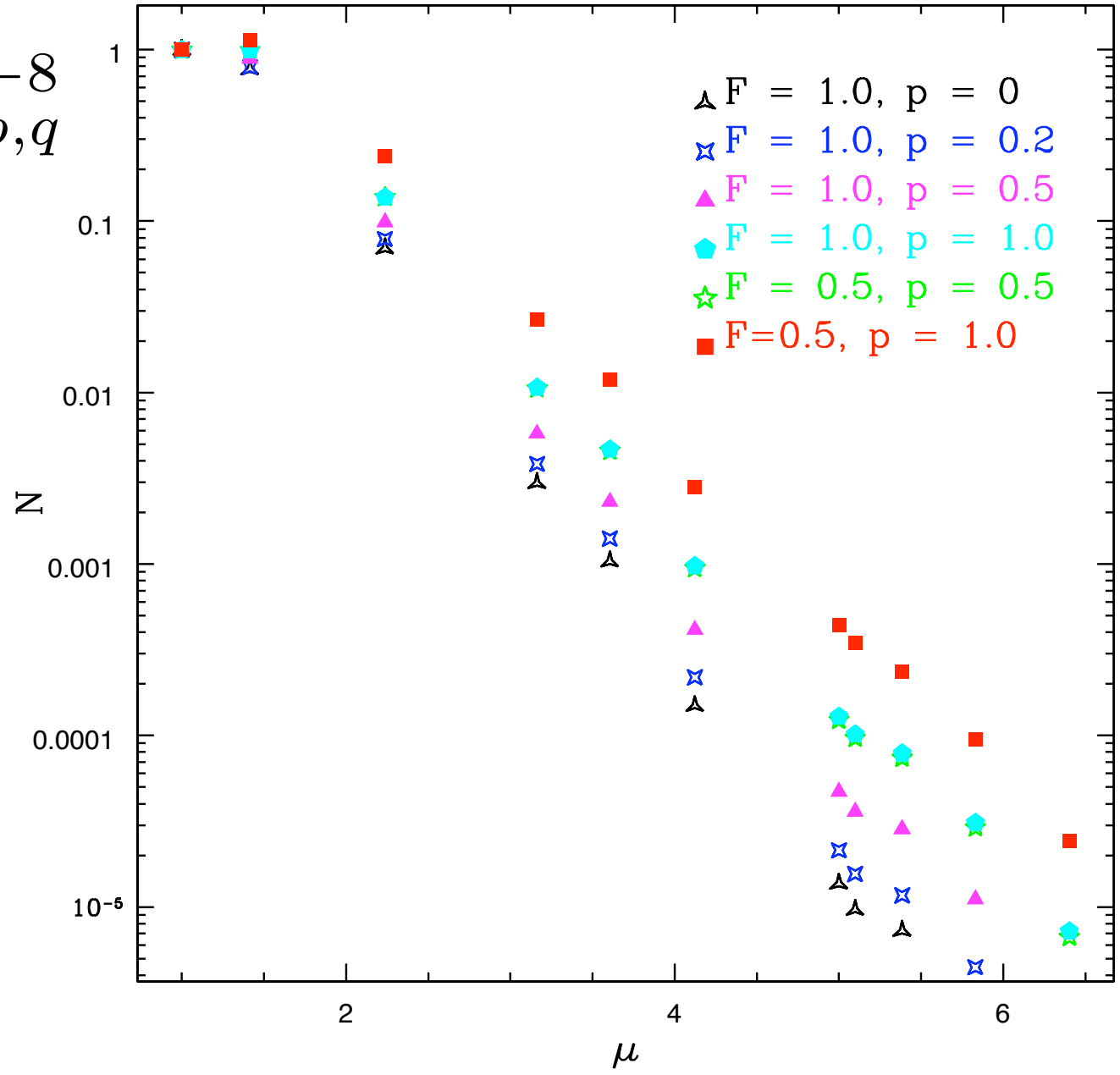


M. Jackson, N. Jones and J. Polchinski, hep-th/0405229

H.T., I.Wasserman, M.Wyman, astro-ph/0503506

Relative density of (p,q) strings

$$n_{p,q} \sim \mu_{p,q}^{-8}$$



Cosmic string tension spectrum in a warped deformed conifold

(Klebanov-Strassler)

One may view the strings as D3-branes wrapping a 2-cycle inside the S^3 at the bottom of the throat.

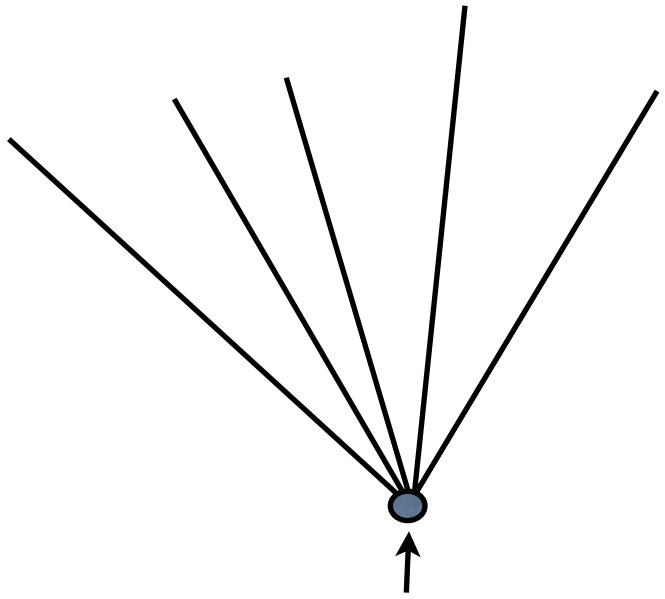
$$T_{p,q} \simeq \frac{h_A^2}{2\pi\alpha'}\sqrt{\frac{q^2}{g_s^2} + (\frac{bM}{\pi})^2 \sin^2(\frac{\pi p}{M})},$$

$$b = 0.93266$$

M is the RR flux wrapping S^3.

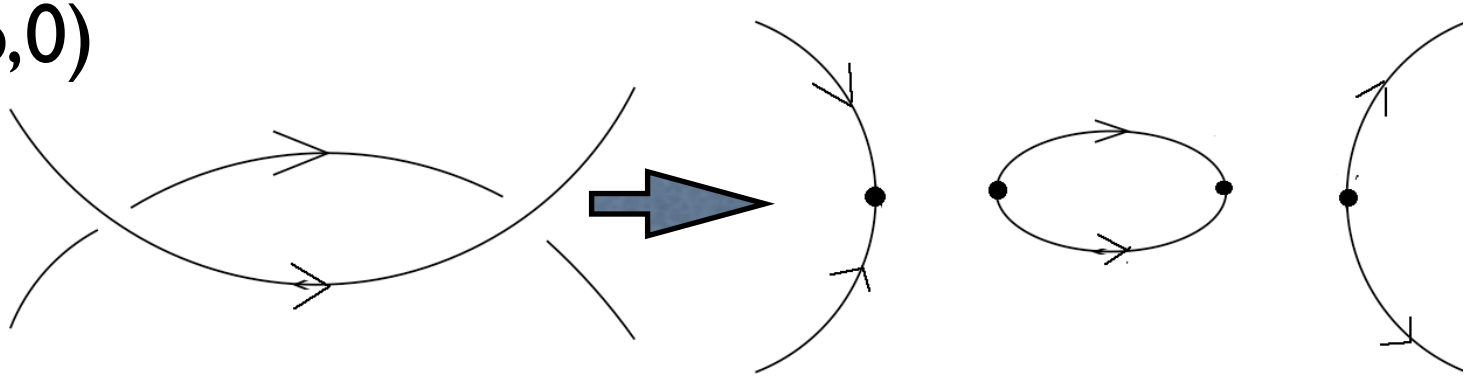
S. Gubser, C. Herzog, I. Klebanov, hep-th/0405282,
H. Firouzjahi, L. Leblond, H.T., hep-th/0603161.

Example :
M=5



A baryon with mass $\sim M h_A/\sqrt{\alpha'}$.

(M-p,0)



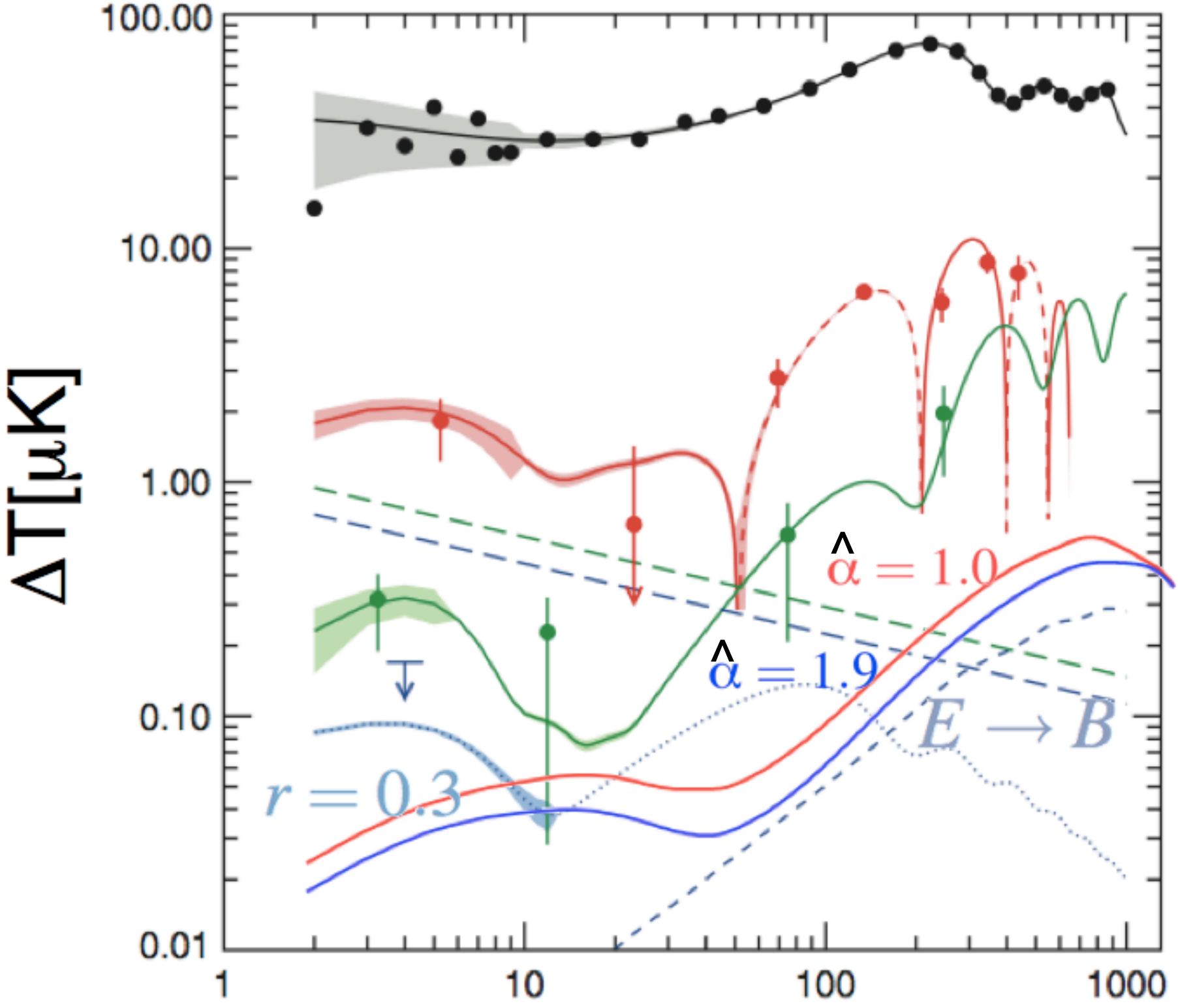
(p,0)

X. Siemens, X. Martin and K. Olum, astro-ph/0005411,
T. Matsuda, hep-th/0509061, ...

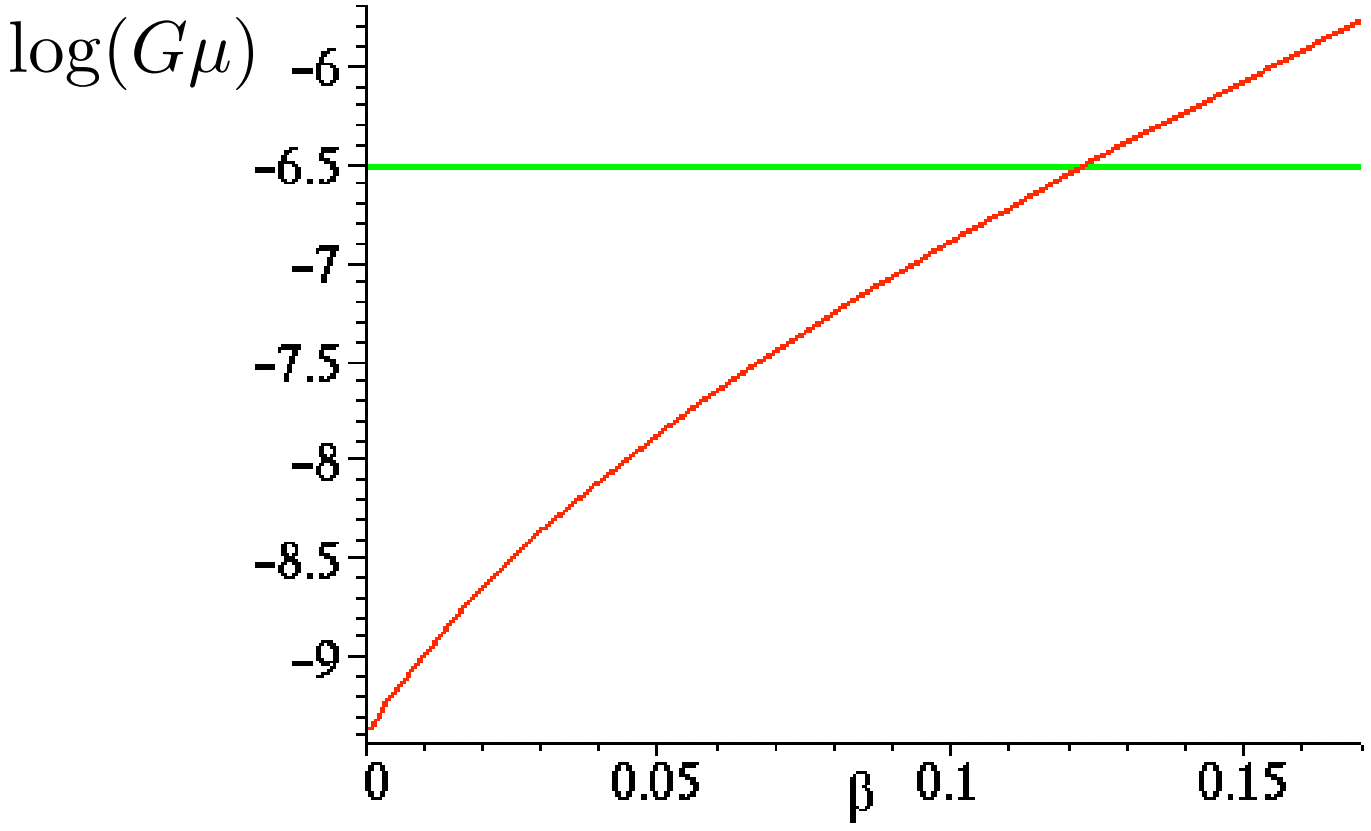
Search for Cosmic Strings

- Lensing
- Cosmic Microwave Background Radiation
- Gravitational Wave Burst
- $\Delta T/T$ (Doppler effect)
- Pulsar Timing
- Stochastic Gravitation Radiation Background

Possible CMB B-mode detection



Cosmic string tension in the KKLMMT scenario



$$5 \times 10^{-7} > G\mu \geq 4 \times 10^{-10}$$

H. Firouzjahi, H.T.

Observational bound from WMAP :

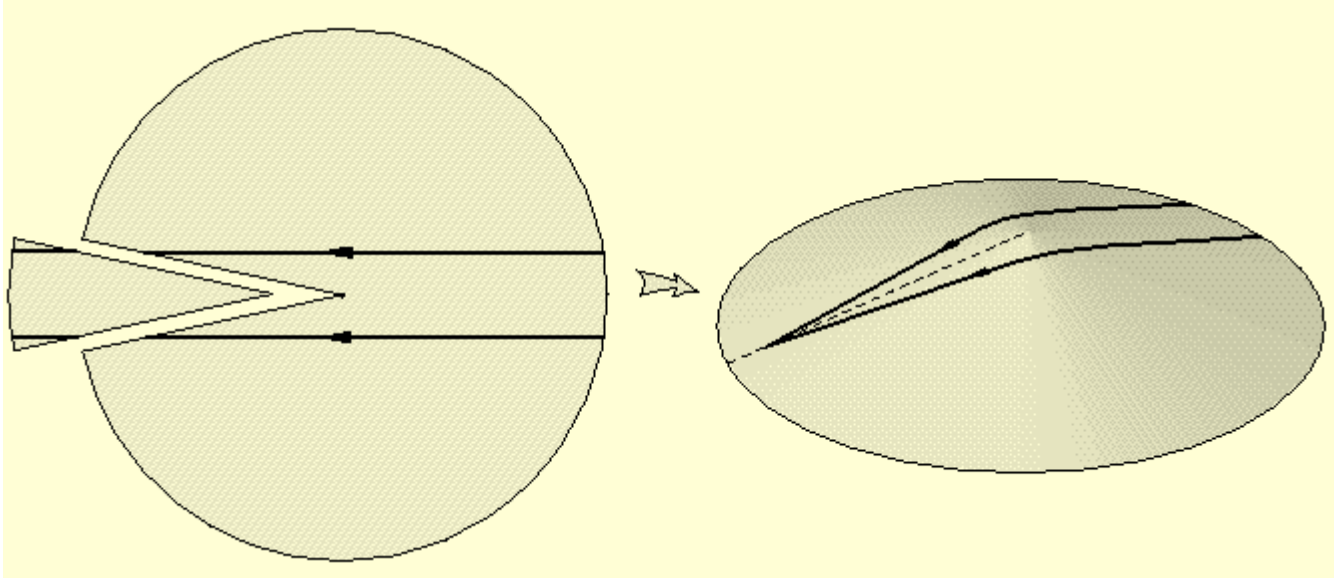
$$5 \times 10^{-7} > G\mu$$

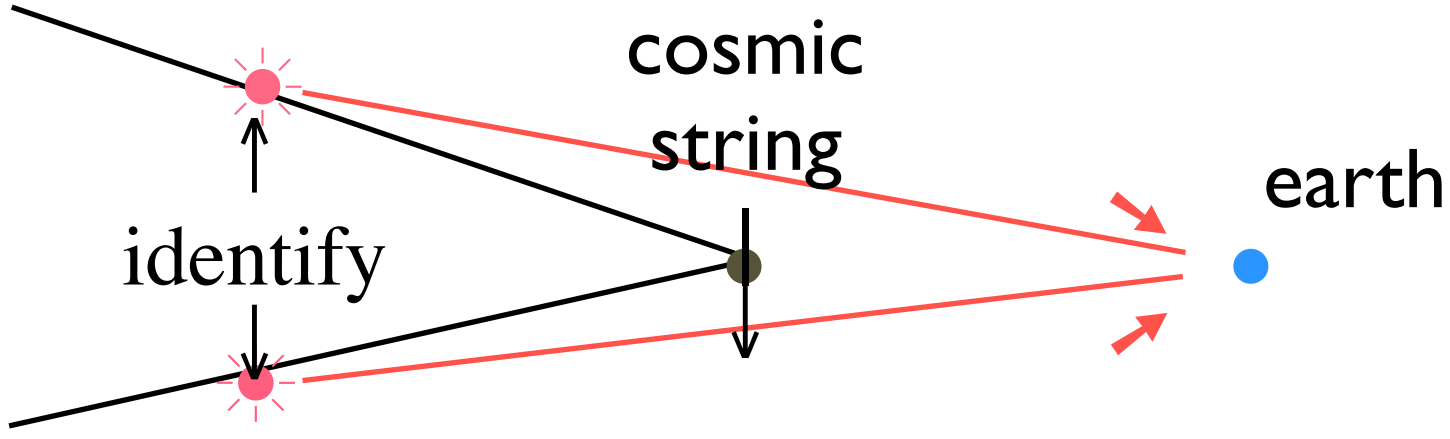
L. Pogosian, I. Wasserman, M. Wyman

Jeong, Smoot

cosmic string lensing

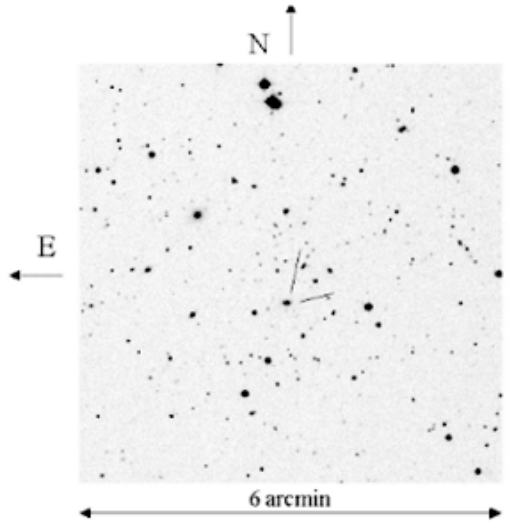
cosmic string introduces a deficit angle

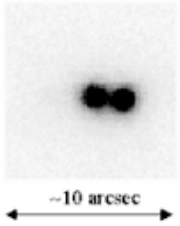


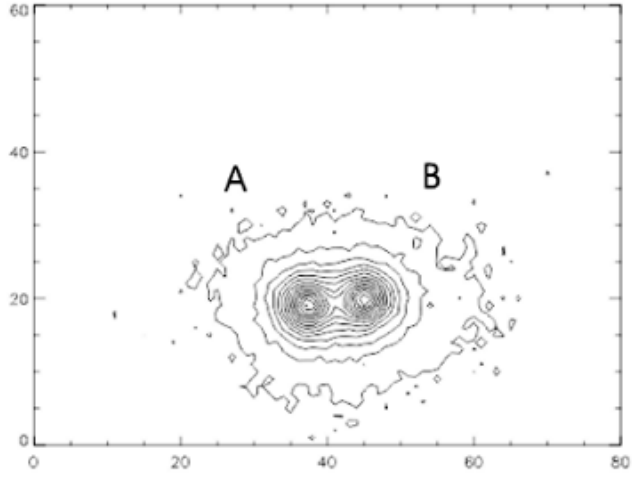


CSL-1

Sazhin etc. astro-ph/0302547

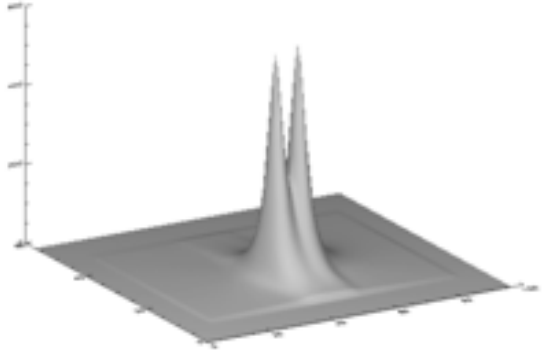


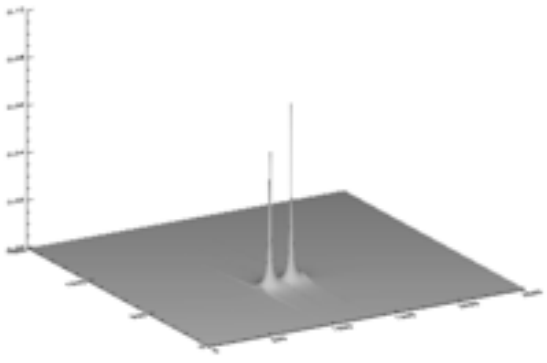


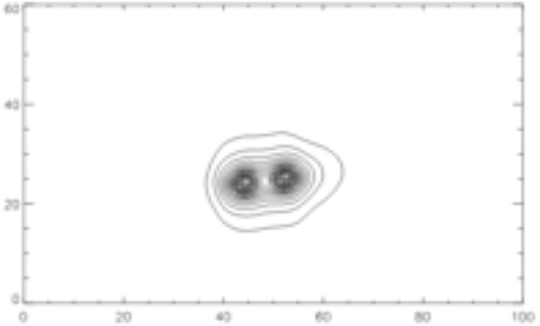


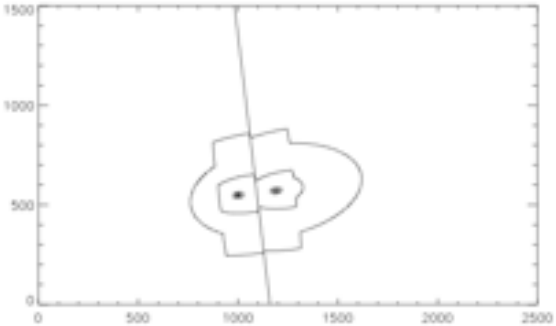
z=0.46 ± 0.008

identical spectra with confidence level above 99.9%







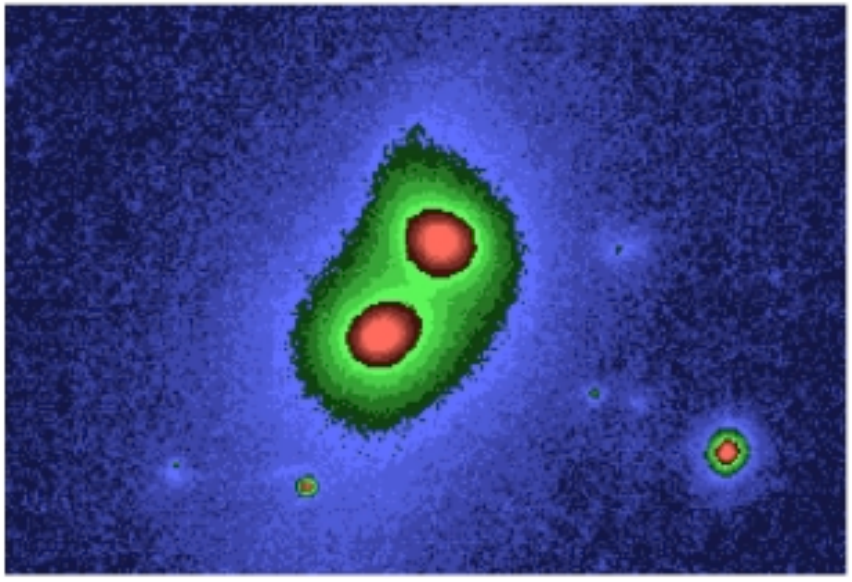


1.9 **arc sec**

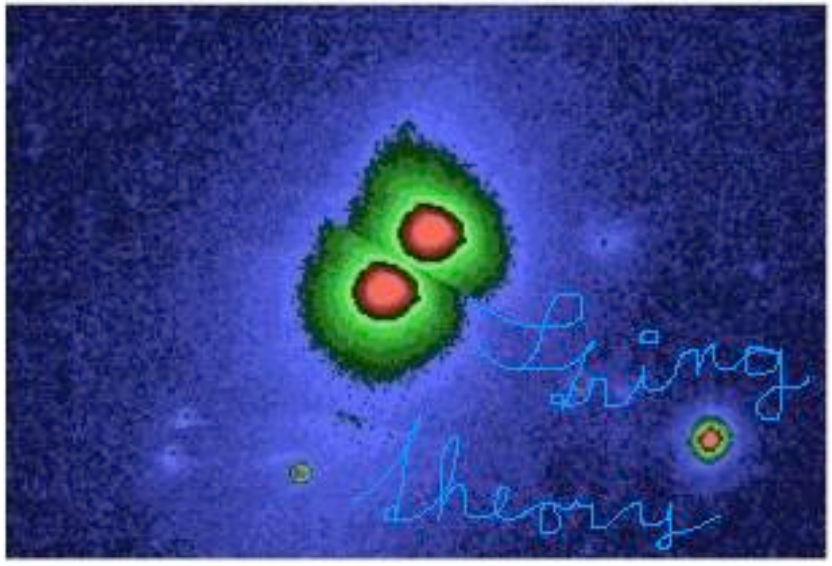
⇓

$G\mu \sim 4 \times 10^{-7}$

Unfortunately not (higher resolution Hubble pictures):



January 2006



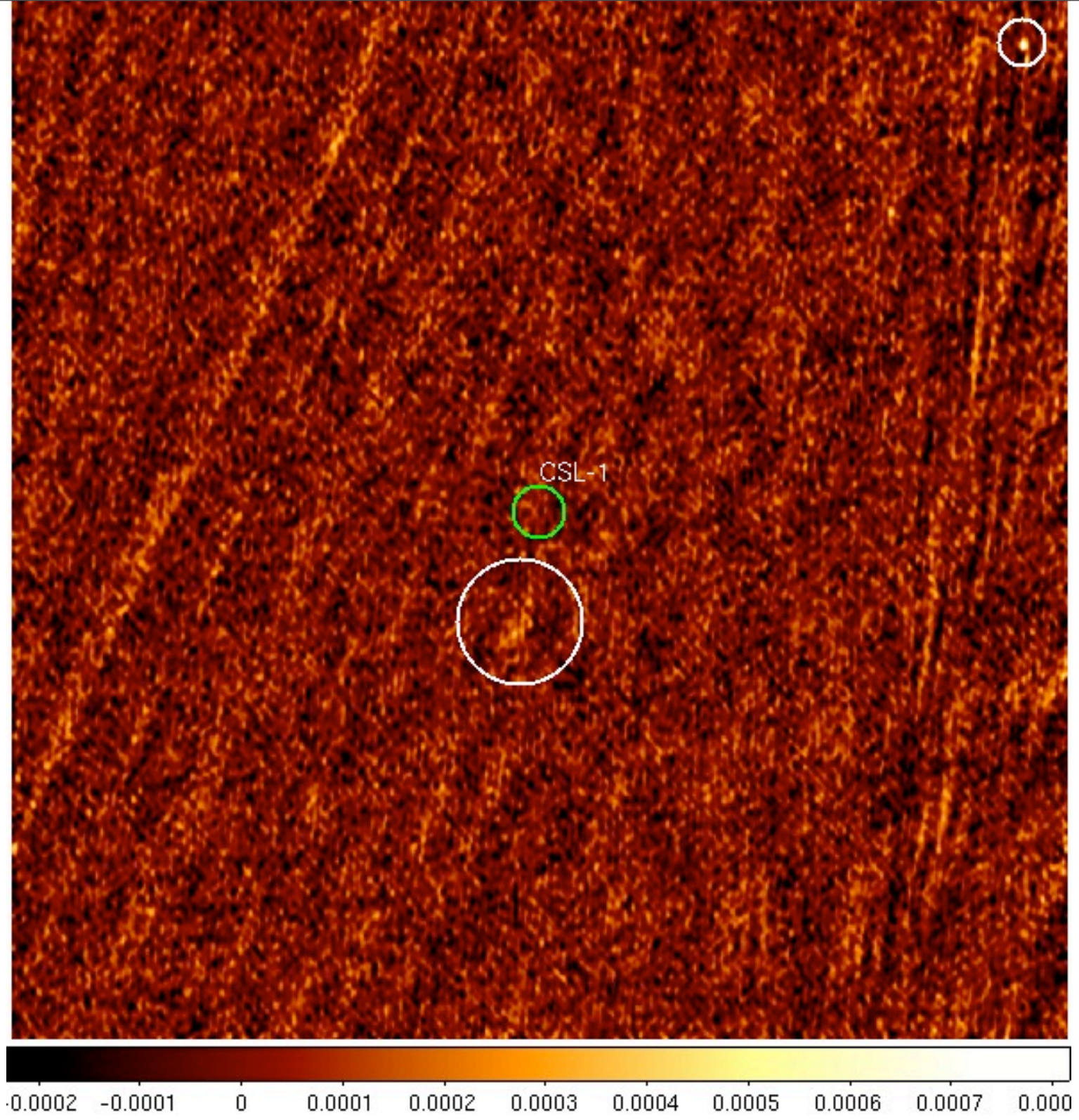
If it is cosmic string lensing

Joe P.
L. Motl

Radio telescope ?

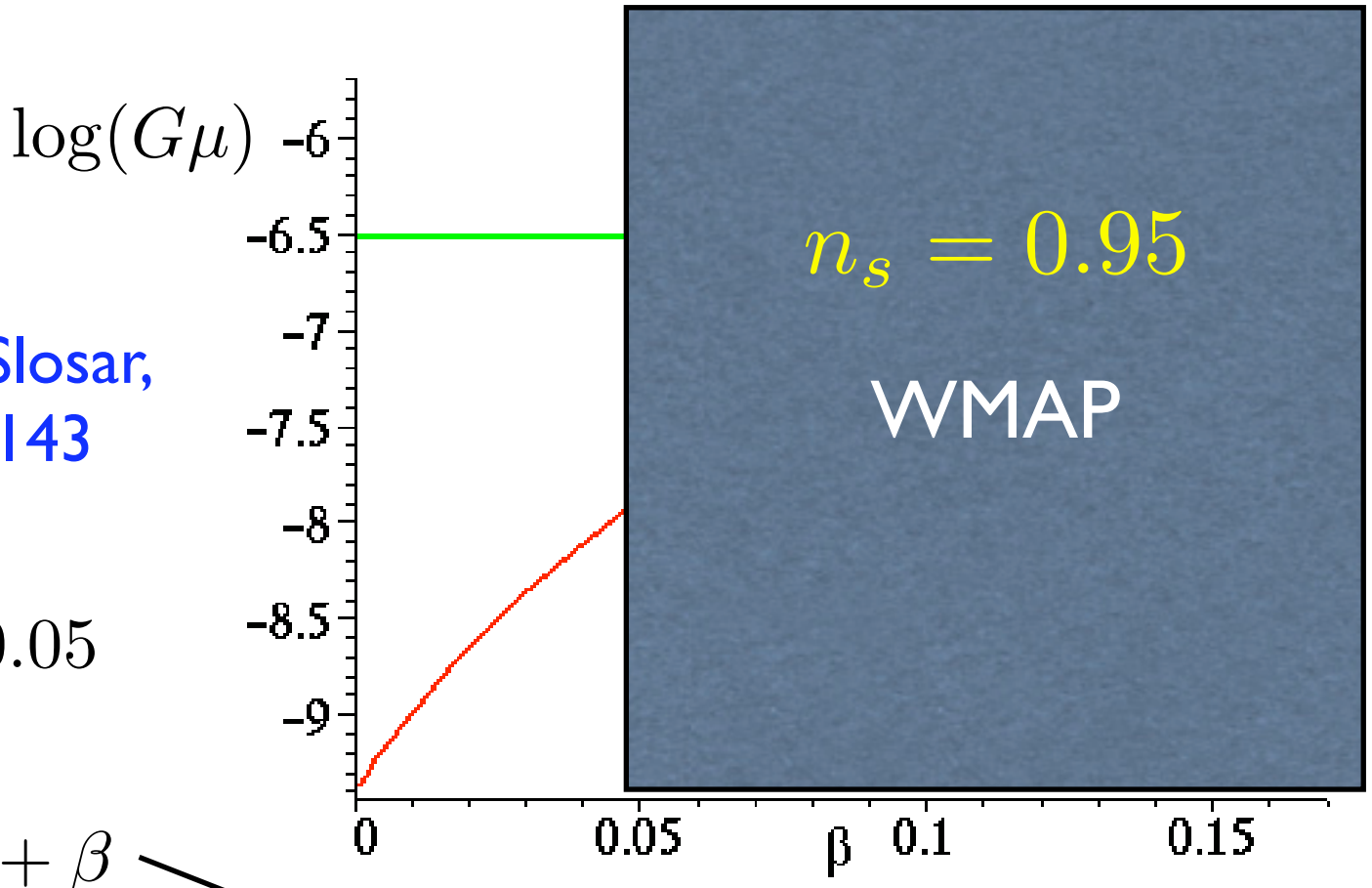
Recall Cowen and Hu.

National Radio Astronomy Observatory



Shami Chatterjee, Jim Cordes, H.T., Ira Wasserman

Bound on cosmic string tension



U. Seljak and A. Slosar, astro-ph/0604143

$0 \leq \beta \leq 0.05$

$n_s \sim 0.98 + \beta$

$\rightarrow n_s \leq 1.03$

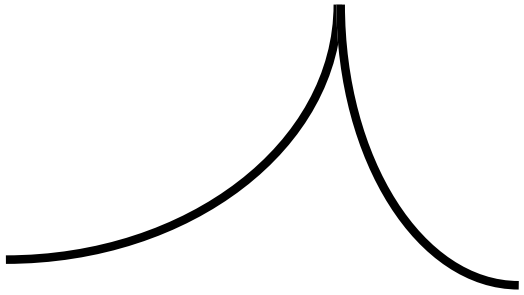
$\log r \sim -8.8 + 60\beta$

$G\mu < 10^{-8}$

$\log G\mu \sim -9.4 + 30\beta$

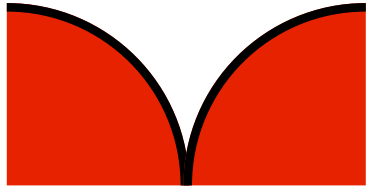
S. Shandera and H.T., 0601099

cusps and kinks
are quite common in string evolution

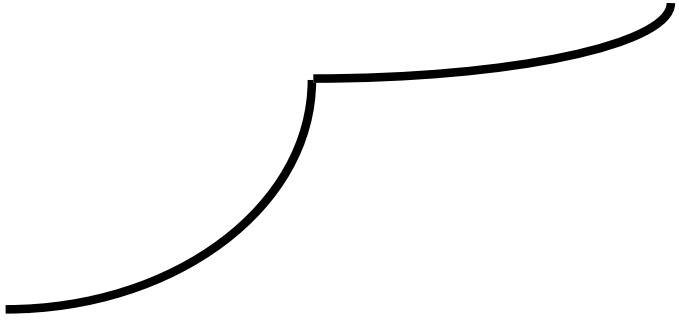


CUSP

$h(t) \sim |t|^{1/3}$



wave form of gravitational wave bursts

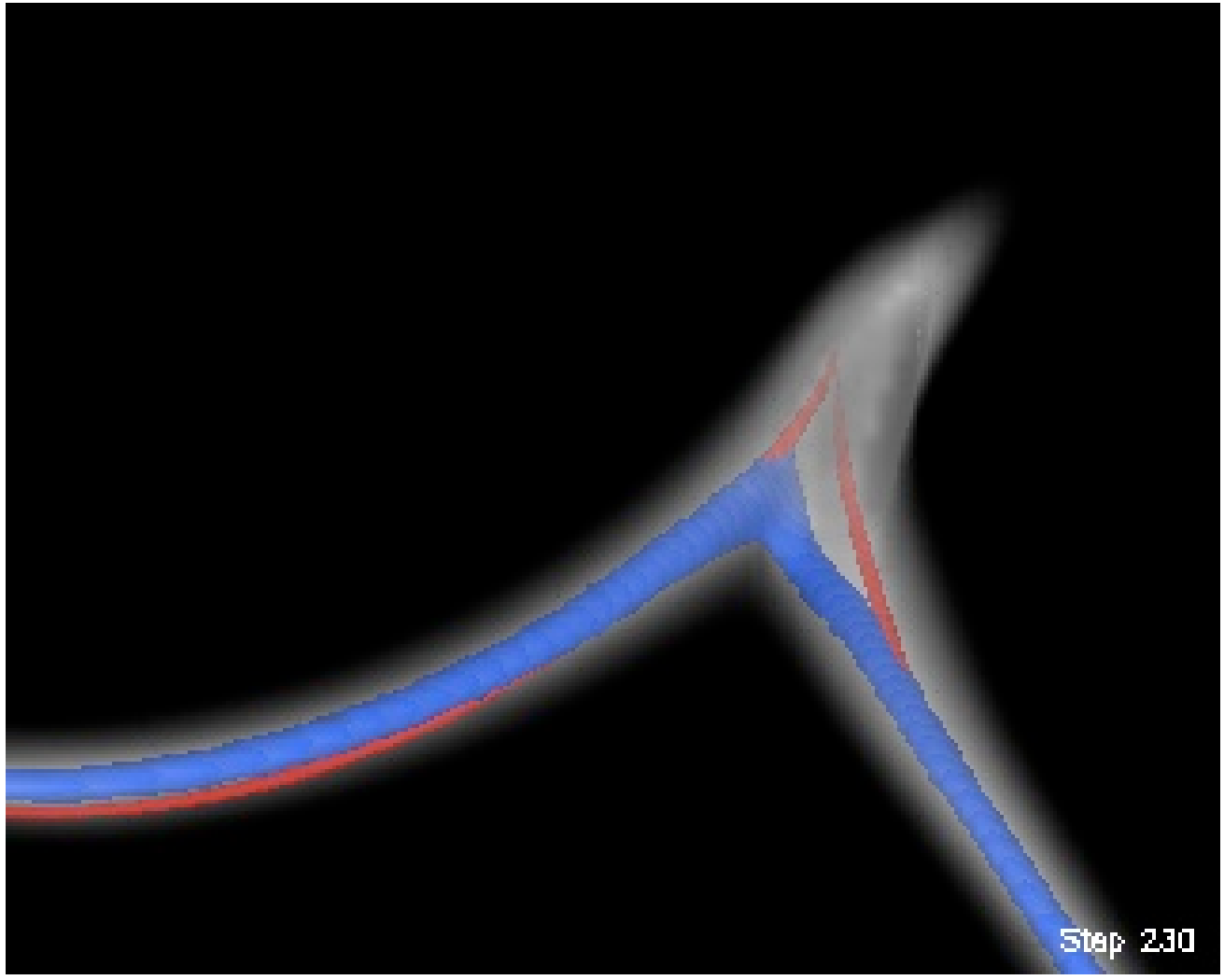


KINK

$h(t) \sim |t|^{2/3}$

Damour and Vilenkin

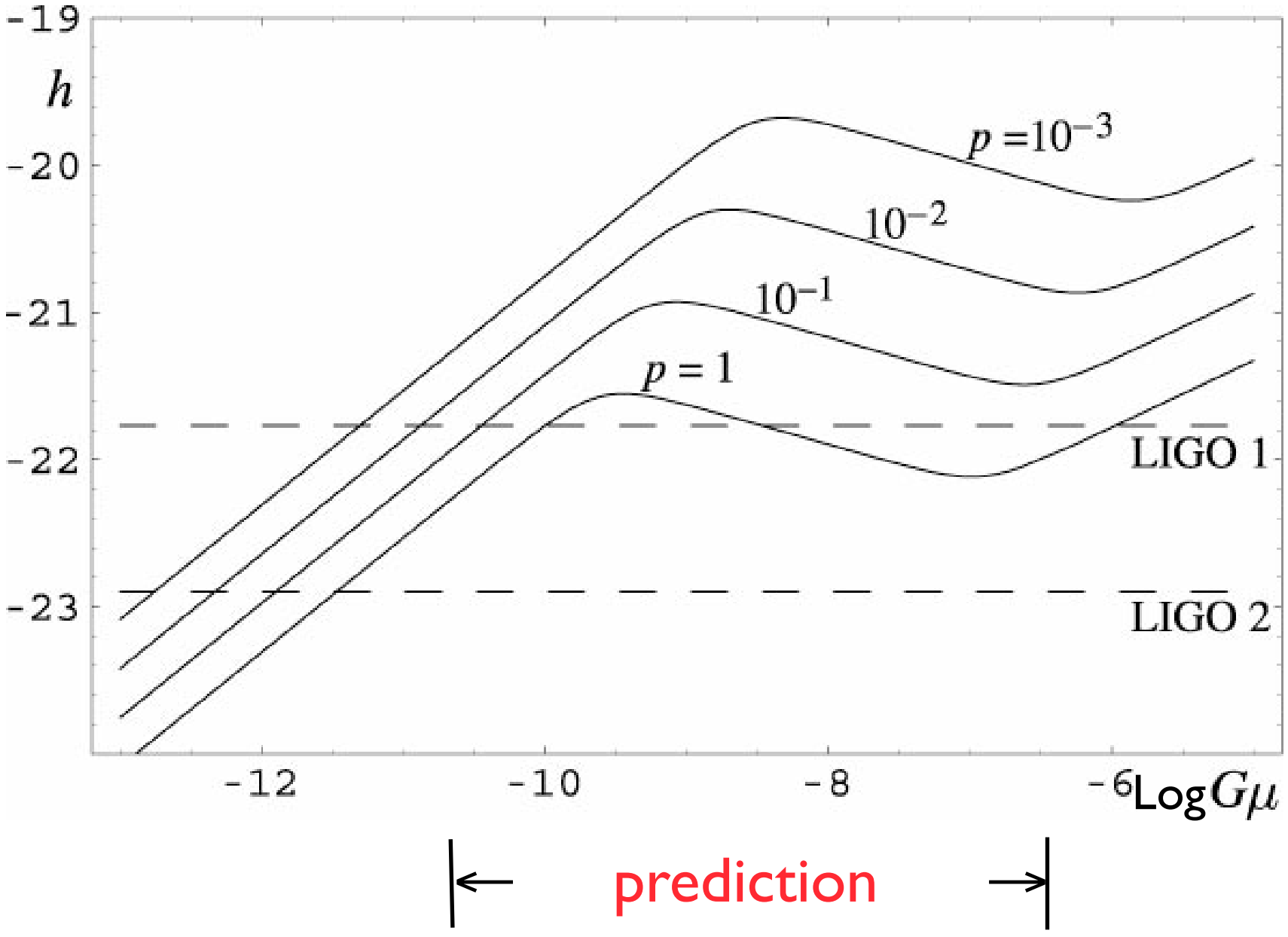
A cusp



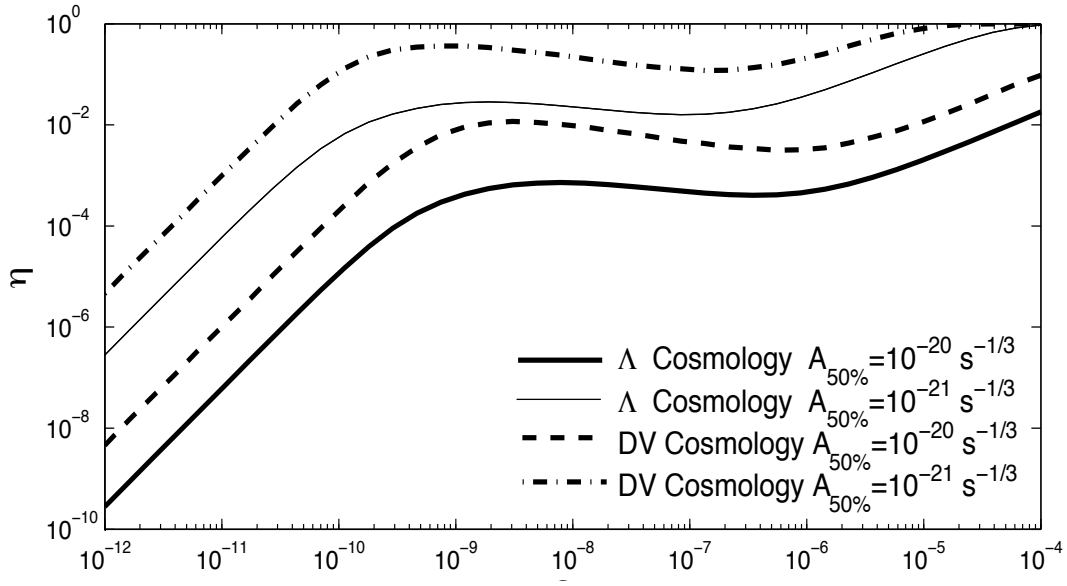
Blanco-Padillo and Olum

gravitational wave radiation from cusps

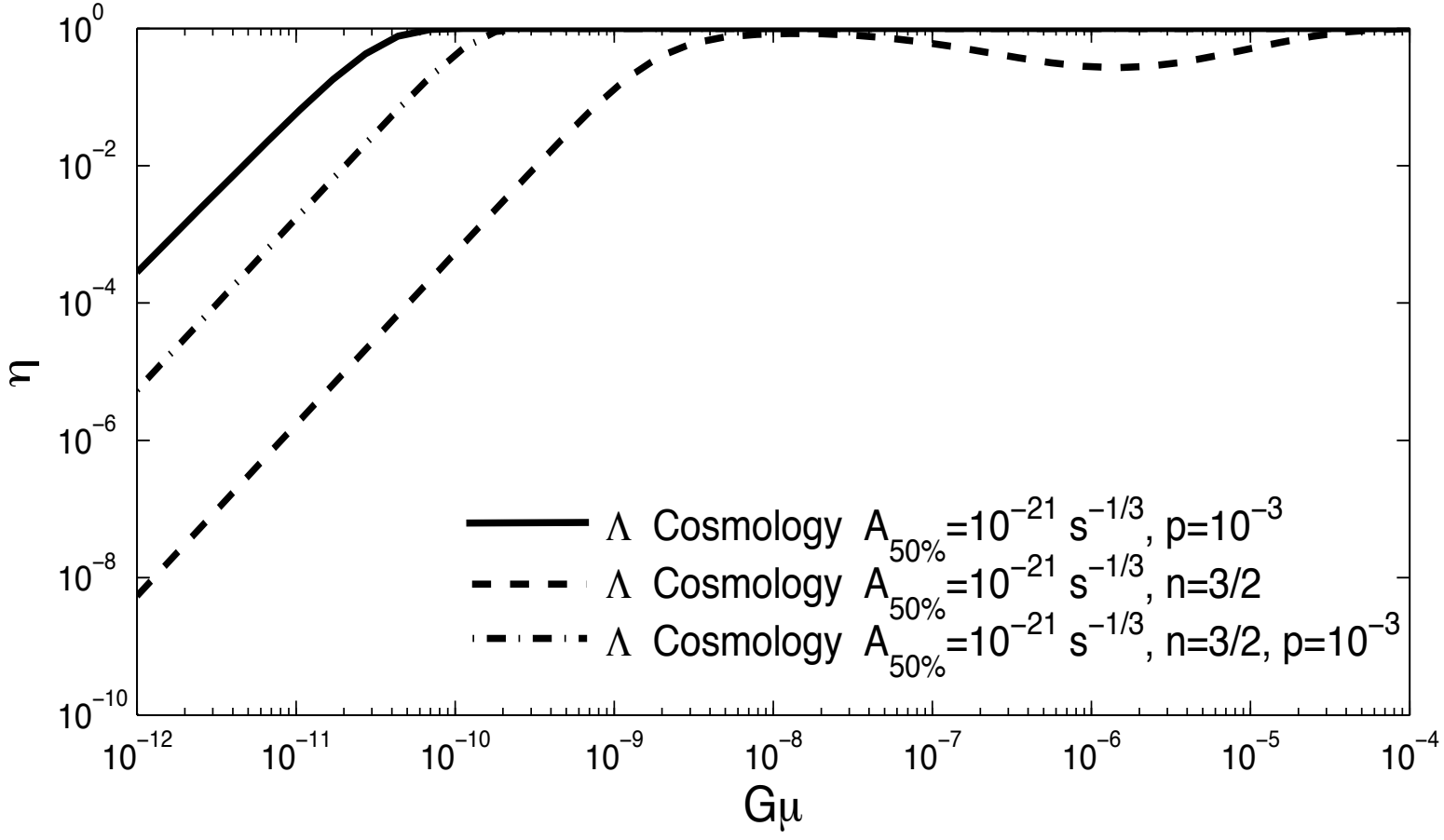
Damour and Vilenkin



prediction

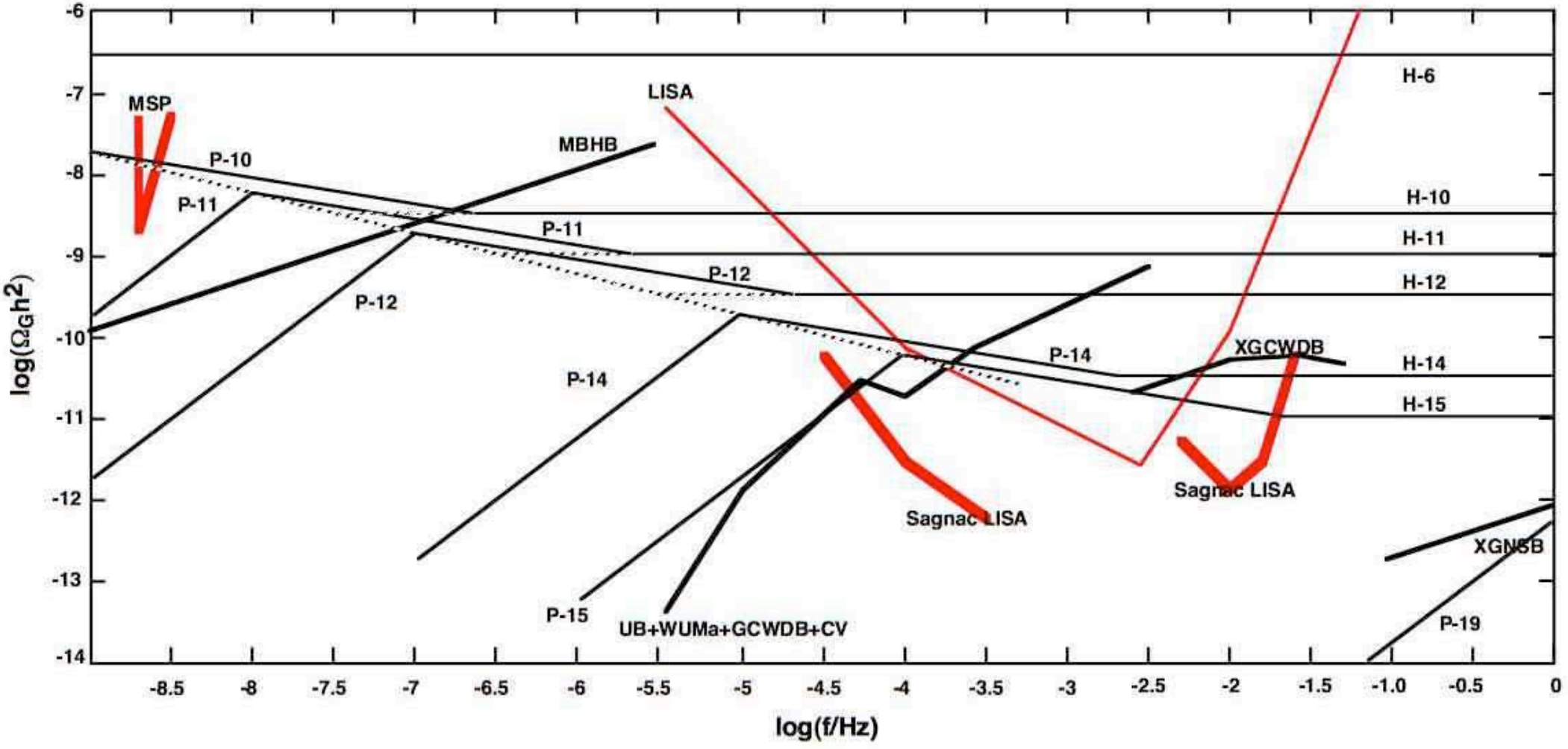


More recent analysis



X. Siemens, J. Creighton, I. Maor, S. Majumder, K. Cannon and J. Reed, gr-qc/0603115

C. J. Hogan, astro-ph/0605567



R. Caldwell and B. Allen, PRD45, 3447 (1992)

Search for Cosmic Strings

- Lensing X
- Cosmic Microwave Background Radiation X
- Gravitational Wave Burst
- ΔT/T (Doppler effect) X
- Pulsar Timing ?
- Stochastic Gravitation Radiation Background
- Micro-lensing
- Cusp Doppler effect ?

Micro-lensing

$$\Theta_E = 8\pi G\mu$$
$$= 1.04 \times 10^{-3} \left(\frac{G\mu}{2 \times 10^{-10}}\right)$$

$$\frac{\Theta_\odot}{\Theta_E} = 4.6 \times 10^{-5} \left(\frac{2 \times 10^{-10}}{G\mu}\right) \left(\frac{100\text{kpc}}{R}\right)$$

$$l_g = \Gamma_R G\mu t_{today} = 40\text{pc} \left(\frac{\Gamma_R G\mu}{10^{-8}}\right) \left(\frac{t_{today}}{13.5\text{Gyr}}\right)$$

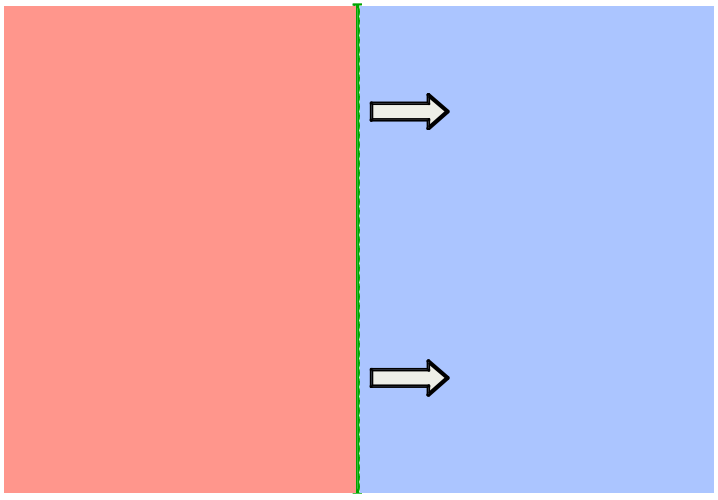
$$t_{osc} \sim \frac{l_g}{c} \sim 135\text{yrs} \left(\frac{\Gamma_R G\mu}{10^{-8}}\right)$$

$$\delta t = 6.3 \times 10^3 \text{sec} \left(\frac{R}{100\text{kpc}}\right) \left(\frac{G\mu}{2 \times 10^{-10}}\right)$$

GAIA : $N_L \sim 0.03$

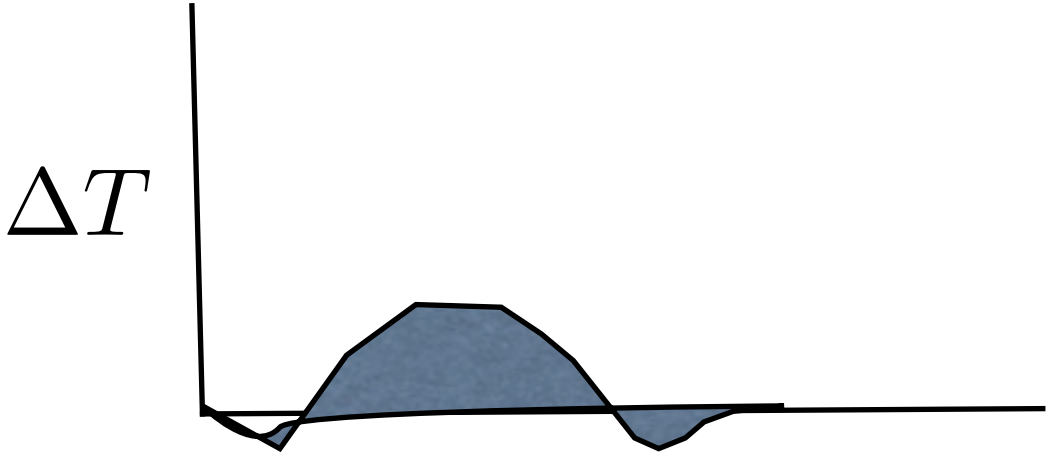
David Chernoff, to appear

Lensing+Doppler by a cusp



A moving string produces a differential redshift
~$8\pi\, G\mu\, v/(c^2\text{-}v^2)^{1/2}$ (lensing+Doppler)

ΔT in 10^{-3} °K or better ?



Superstring theory may be tested

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- The string tensions have the right values so they are compatible with all present day observational bounds and yet can be detected in the near future.

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- Instead of searching for tiny particles or signatures in accelerators, such superstrings may stretch across the universe.
- The string tensions have the right values so they are compatible with all present day observational bounds and yet can be detected in the near future.
- Their (p,q) properties give them quite distinct signatures.

Superstring theory may be tested

- Instead of searching for tiny particles or signatures in accelerators, such superstrings may stretch across the universe.
- The string tensions have the right values so they are compatible with all present day observational bounds and yet can be detected in the near future.
- Their (p,q) properties give them quite distinct signatures.
- More work is needed on this and other brane inflationary and cosmic string scenarios. A typical stringy vacuum has a number of axions and corresponding strings.